

PALS 10th Anniversary Workshop, September 22-24, 2010

**Laser plasma X-ray and EUV sources for application in micro-
and nanoprocessing materials and nanoimaging**

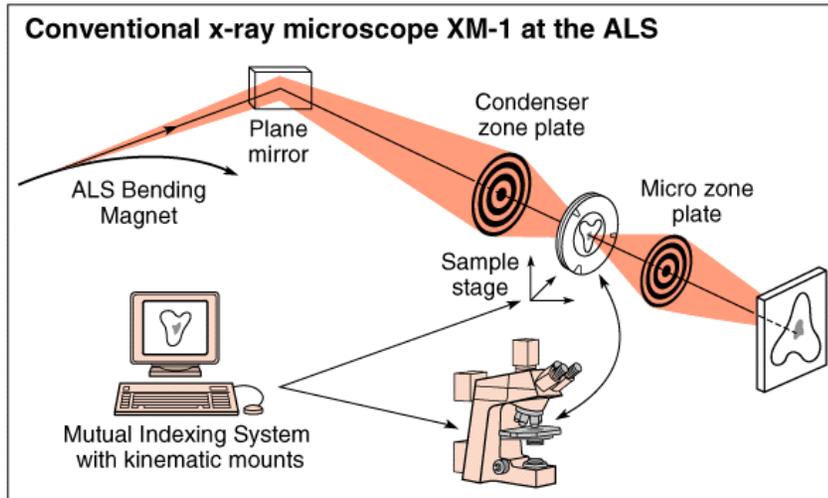
Henryk Fiedorowicz

*Institute of Optoelectronics,
Military University of Technology,
Warsaw, Poland*

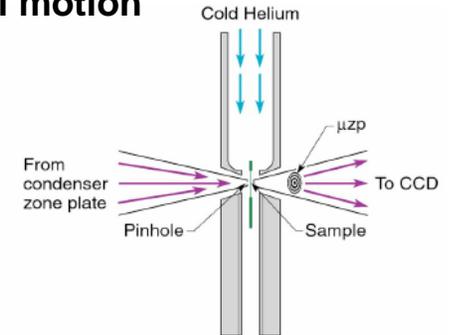


- **COLLABORATIVE EXPERIMENTS AT PALS**
 - laser plasma X-ray source for a single-shot exposure microscopy,
 - direct photo-etching with soft X-rays,
- **MICRO- AND NANOPROCESSING MATERIALS**
 - microstructuring polymers ,
 - modification of polymer surfaces,
- **IMAGING WITH NANOMETER RESOLUTION**
 - EUV microscope based on a Fresnel optics,

X-ray Microscopy based on a Fresnel Optics

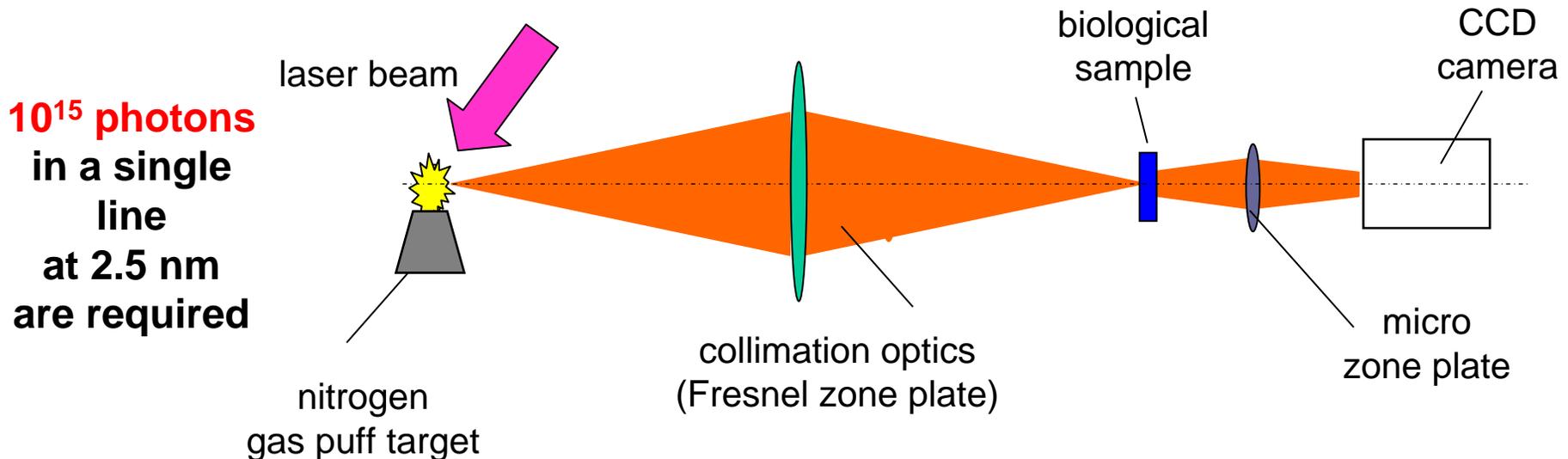


- mitigation of radiation dose effects
- reduction of thermal motion

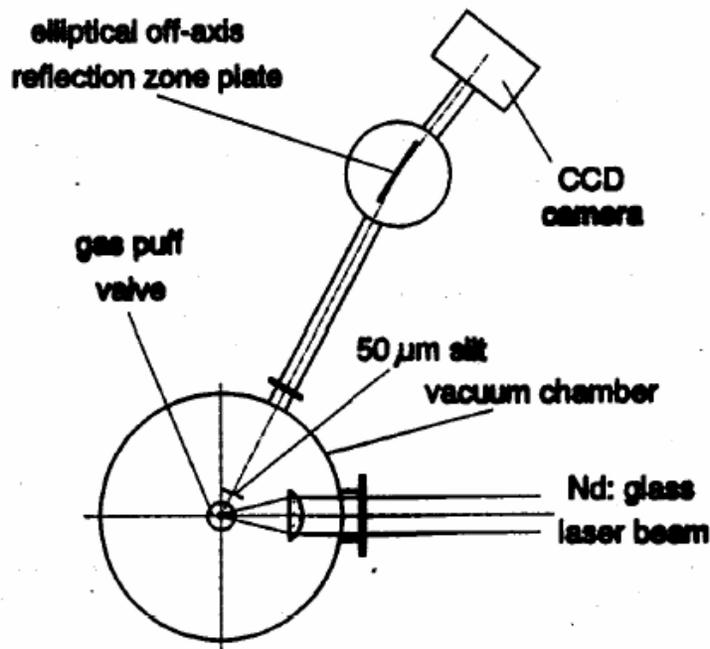


Helium passes through LN, is cooled, and directed onto sample windows

Single-shot exposure soft X-ray microscope with a laser plasma source



Soft X-ray Emission from a Laser-Irradiated Nitrogen Gas Puff Target

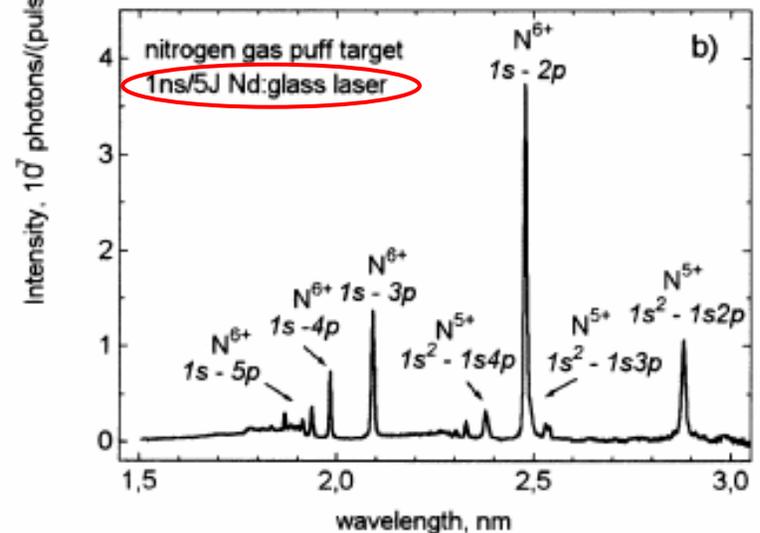
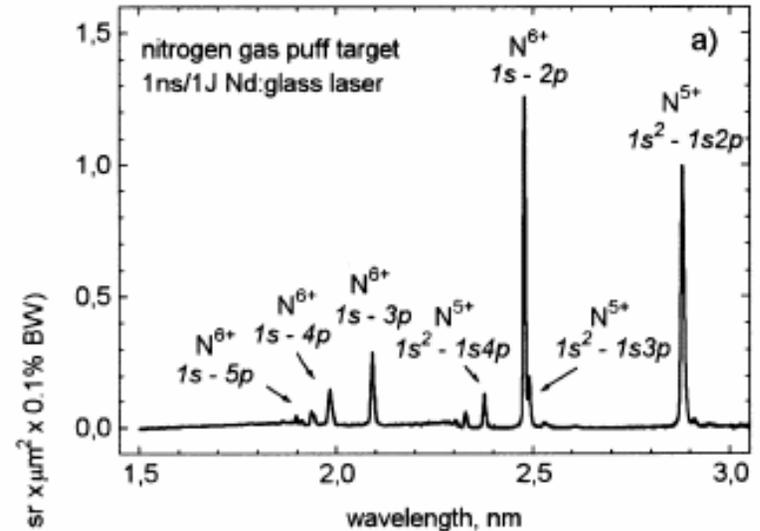


Absolute photon number in the line from the 1s–2p transition in N^{6+}

1.3×10^{13} photon/pulse-sr

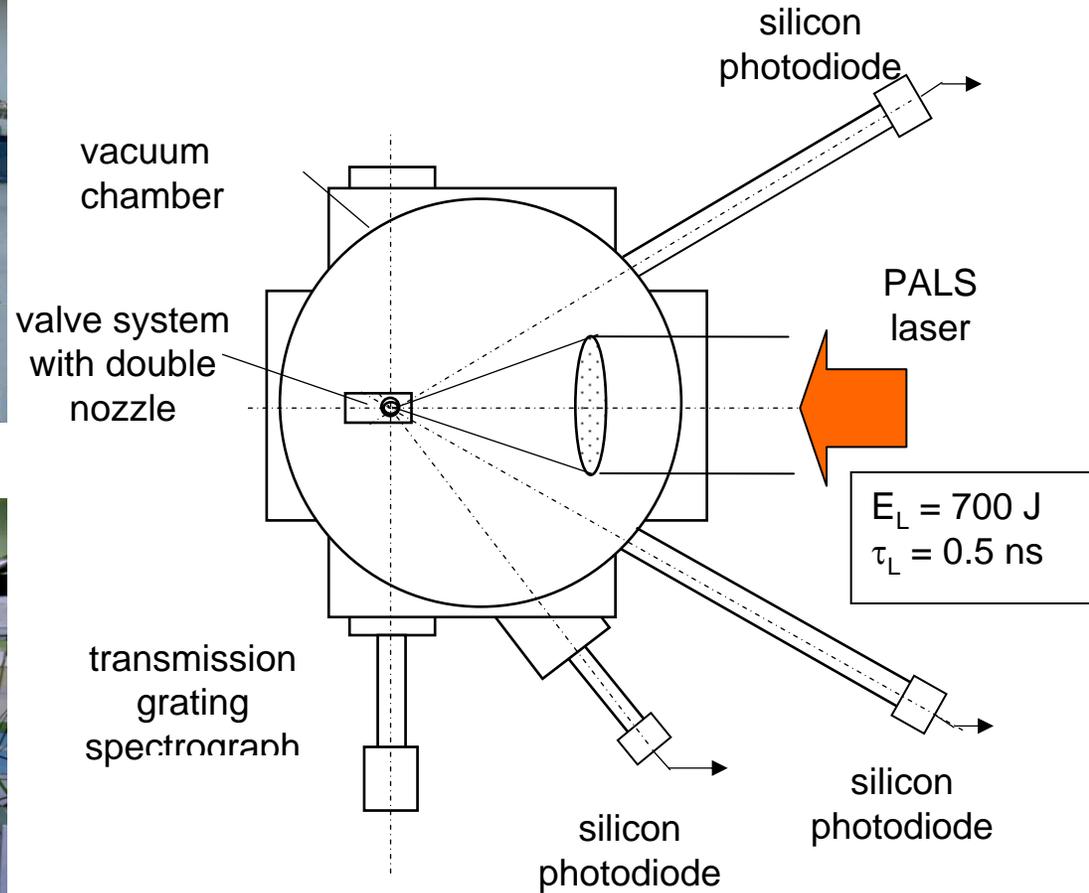
Appl. Phys. B 67 (1998) 391

Frankfurter Allgemeine Zeitung (2.12.1998)



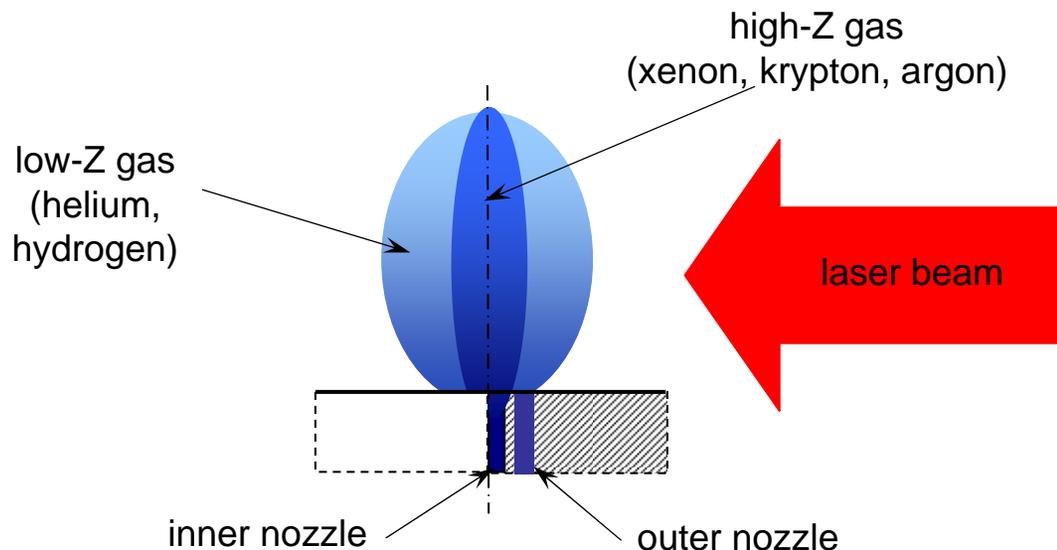
Prague Asterix Laser System (PALS)

Experimental setup

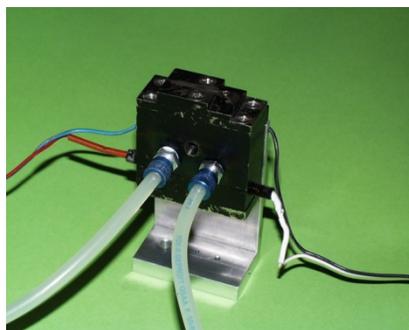
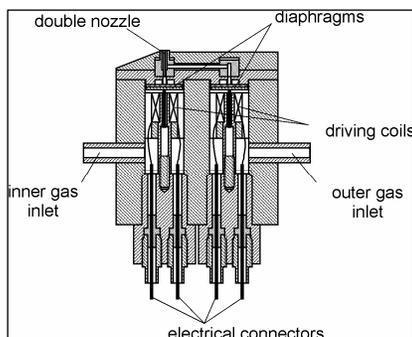


Double-Stream Gas Puff Target

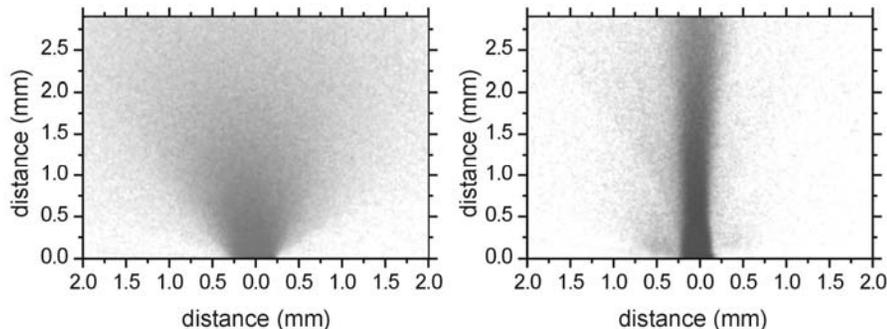
- schematic of a double-stream gas puff target



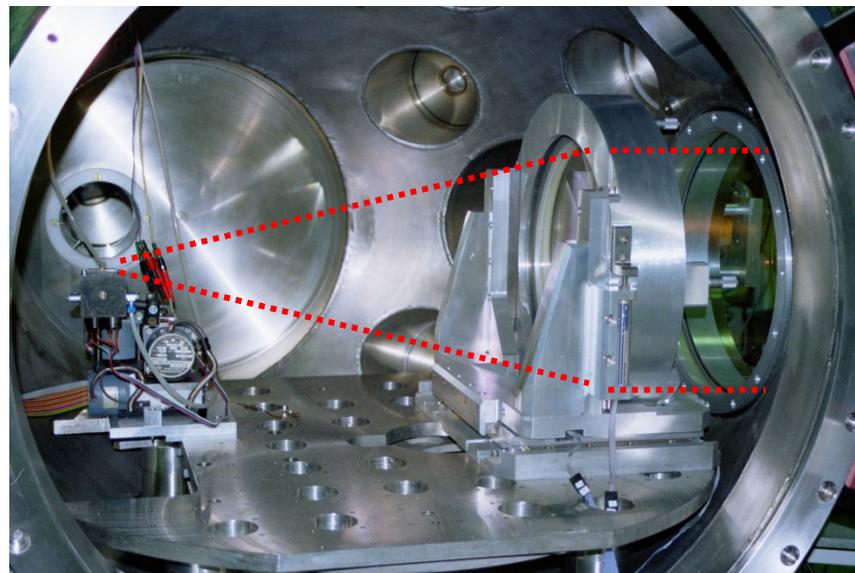
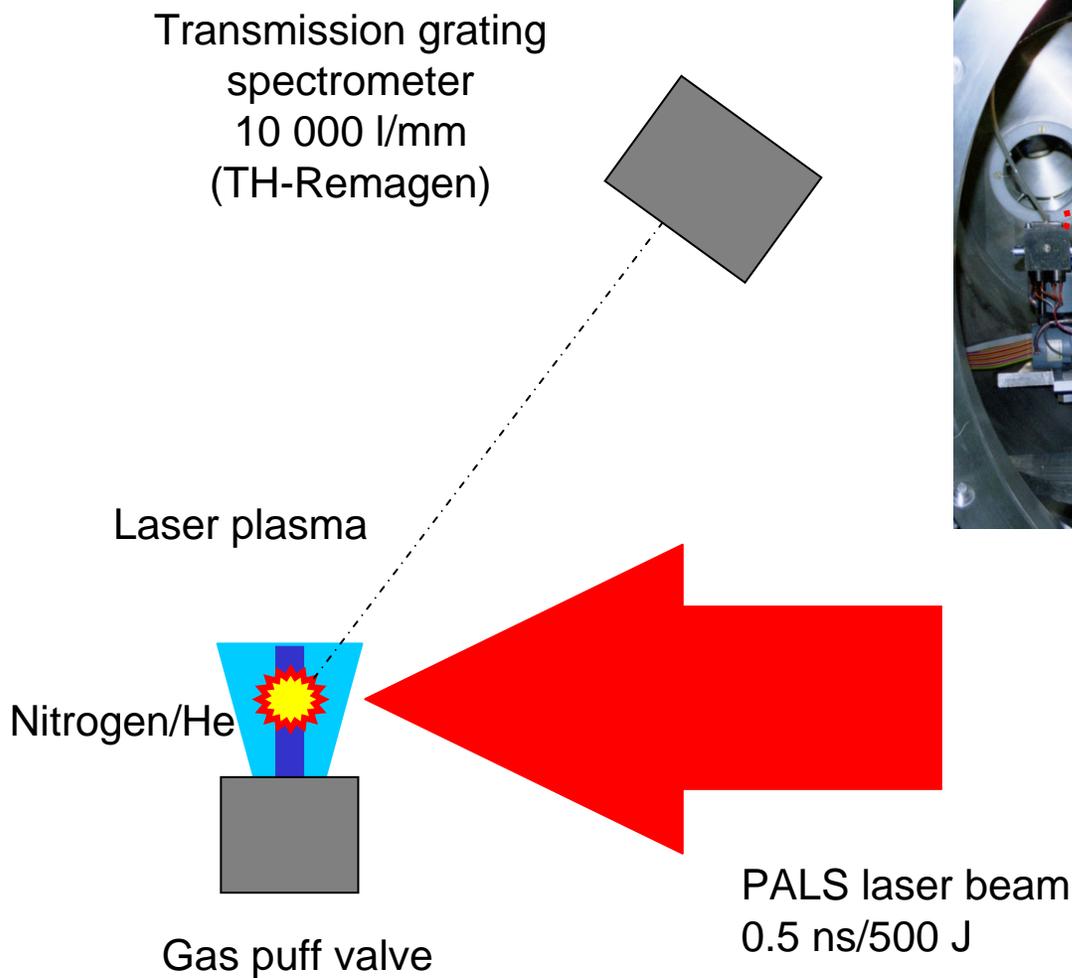
- electromagnetic valve system



- X-ray backlighting images



Soft X-ray Emission Studies

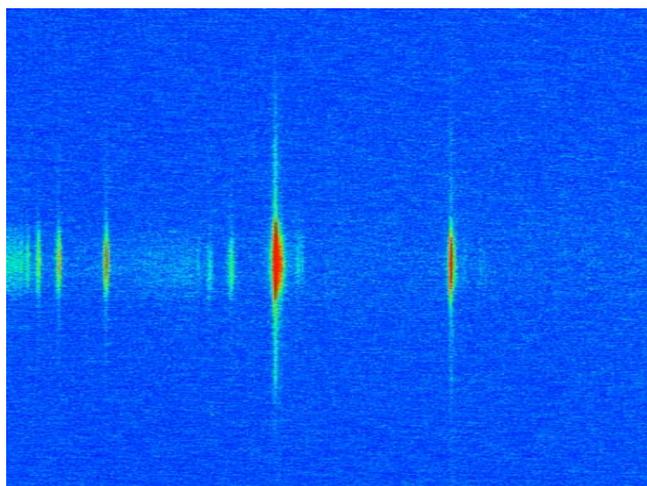


Soft X-ray Emission from Nitrogen

PALS, Prague

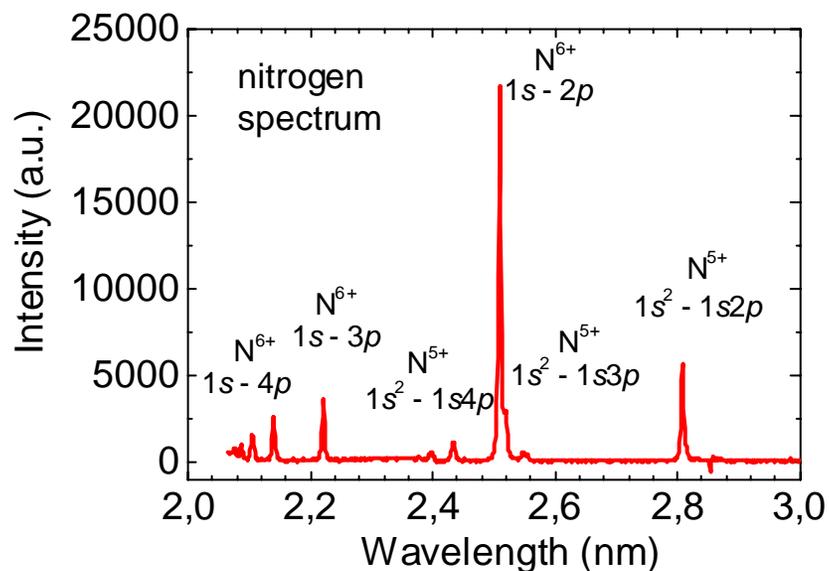
IOE, Warsaw

TH, Remagen



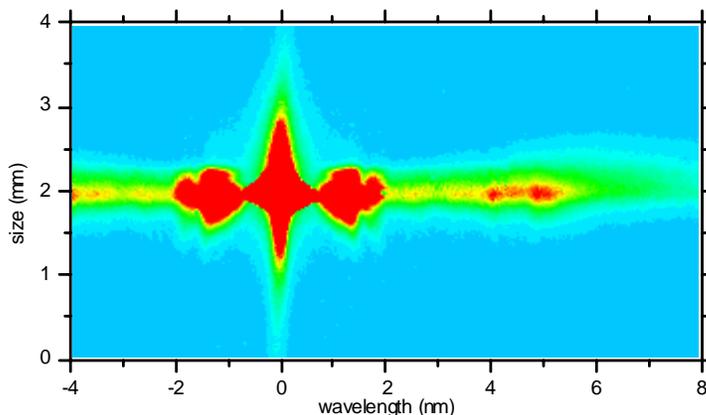
CCD camera
readout

5×10^{15} photons
at 2.5 nm
measured
for
laser energy
540 J



SOFT X-RAY EMISSION FROM XENON

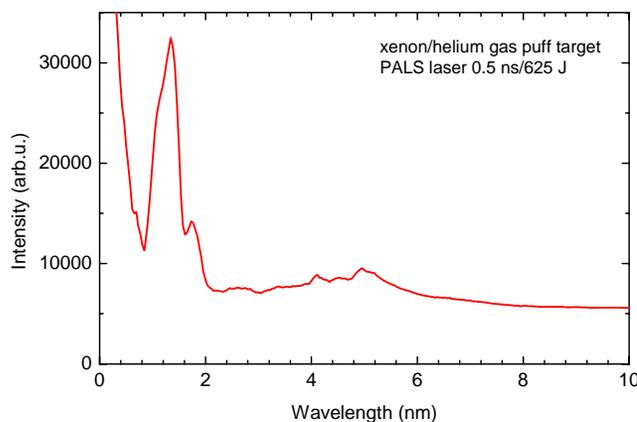
Soft x-ray spectrum for xenon/helium gas puff target irradiated with the PALS laser



(0.5 ns/540 J)

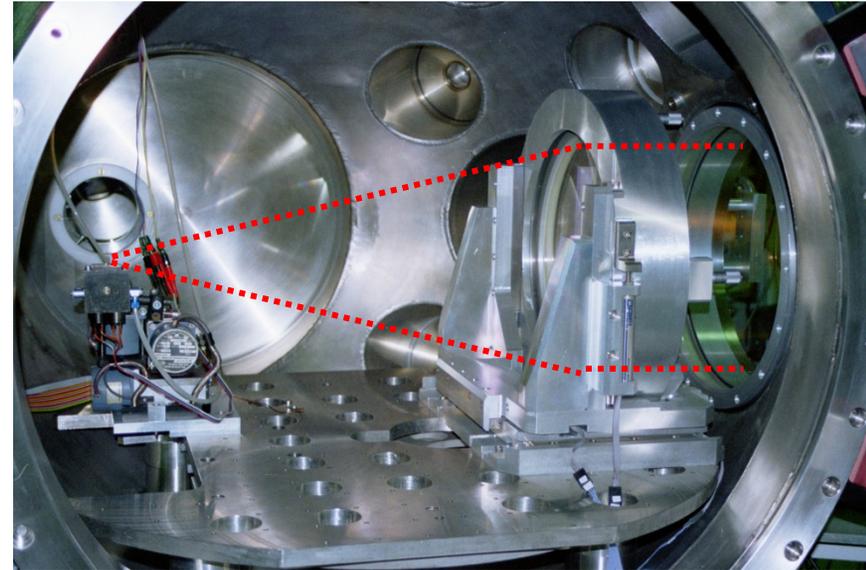
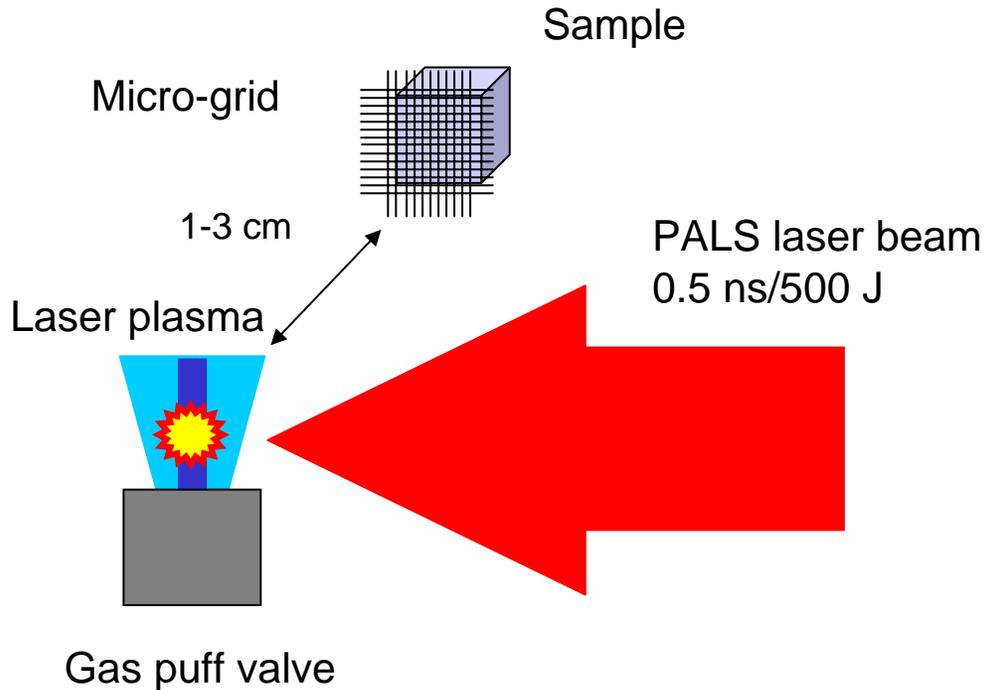
X-ray emission measured with the silicon photodiode

0.5 nm	10 J	2%
1-2 nm	160 J	30%
3-7 nm	160 J	30% (?)



Soft X-ray Direct Photo-Etching

Schematic of the experiment (proposed by L. Juha)

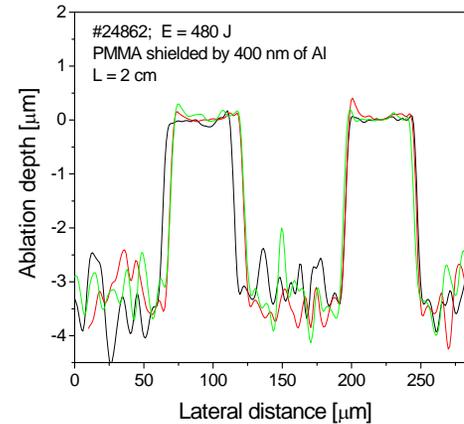
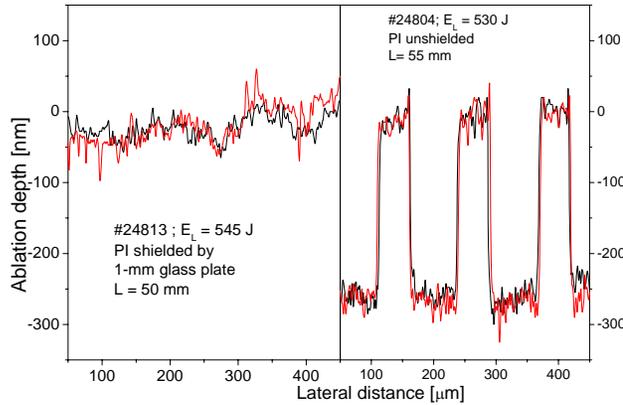


Advantages of using the gas puff target

- elimination of target debris,
- reduction of ions,
- high conversion efficiency.

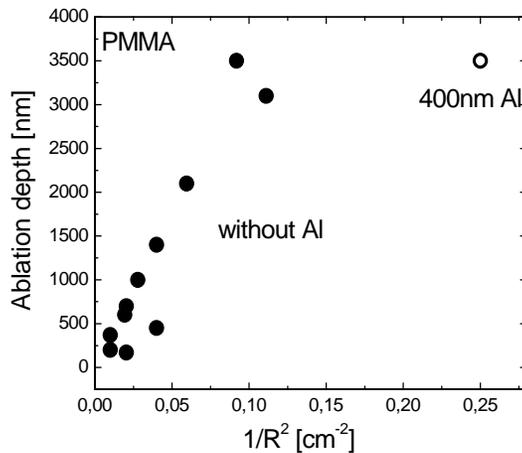
Soft X-ray Photo-Etching of Polymers

Depth profiles of the structures formed by soft X-ray photo-etching using LPXS

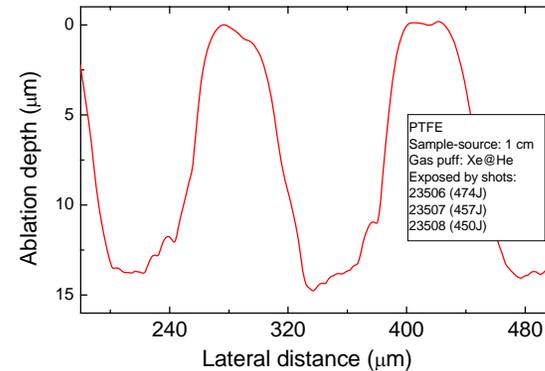


~3 μm

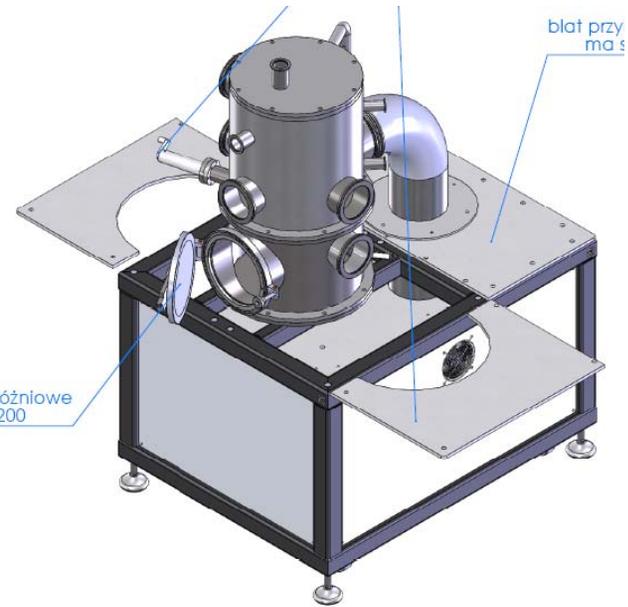
Ablation depth vs sample-source distance



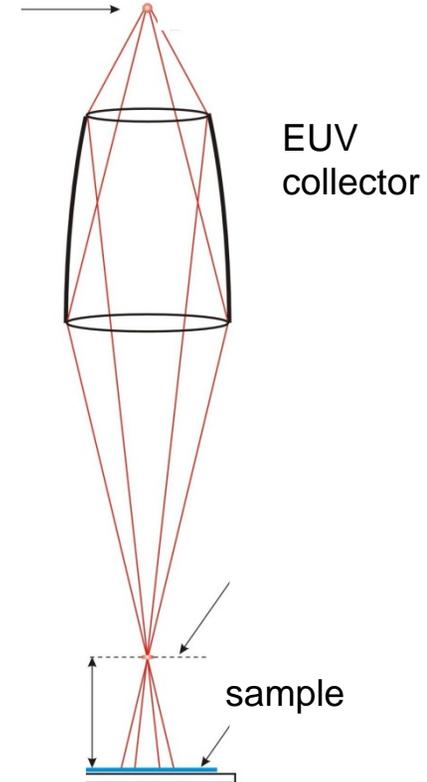
Soft X-ray ablation with multiple exposition



Laser plasma EUV source for processing polymers



EUV source

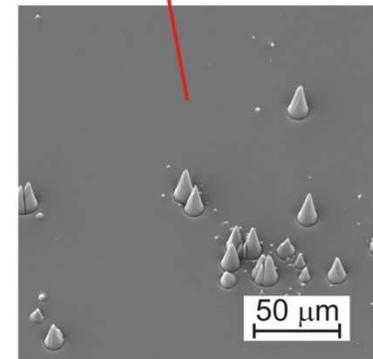
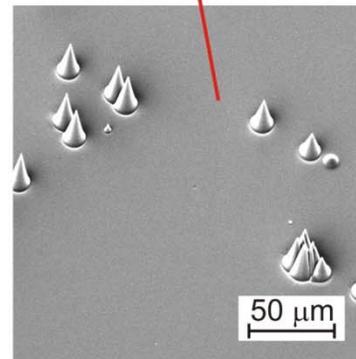
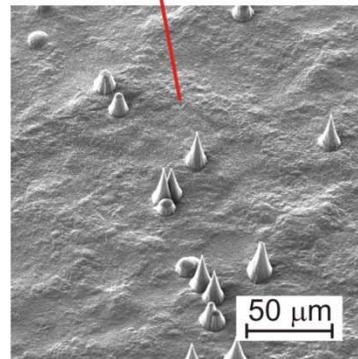
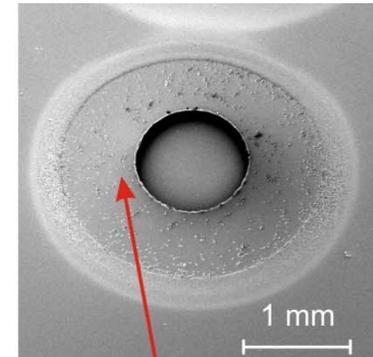
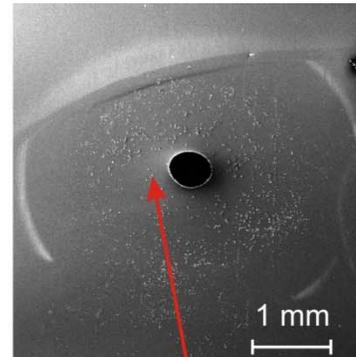
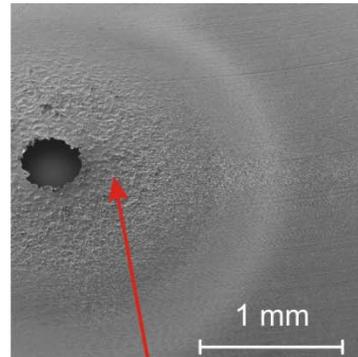


EUV Photo-Etching Polymers

50 μm thick polymer foils, 2 min irradiation, 10 Hz operation rate, GI mirror

Ablation accompanied by cones formation

- ablation rates
100nm/pulse
1 $\mu\text{m/s}$ (10Hz)
100 $\mu\text{m/s}$ (1kHz)



Polytetrafluoroethylene,
PTFE

Fluorinated ethylene –
propylene, FEP

Poly (methyl
methacrylate), PMMA

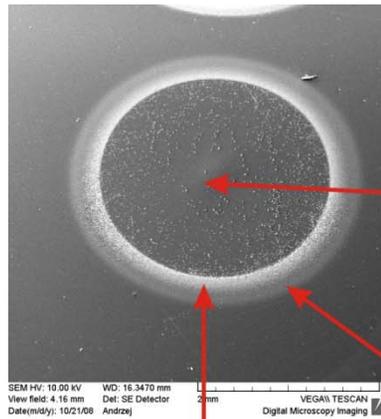
Suggested explanations for cones formation:

- shielding by impurities,
- carbon enrichment
- local shift of the ablation threshold,

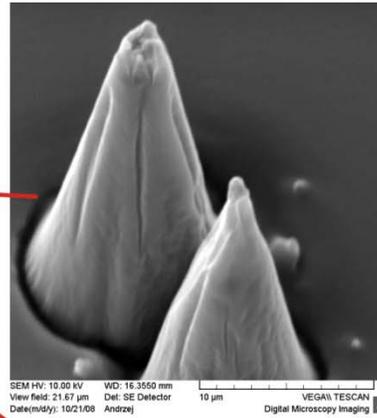
Polymethyl Methacrylate (PMMA)

SEM images of PMMA irradiated in the focal plane of Mo coated ellipsoidal collector, Xe plasma radiation, repetition rate 10 Hz

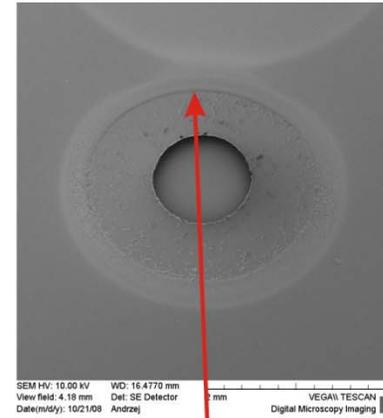
1 min exposure



2 mm

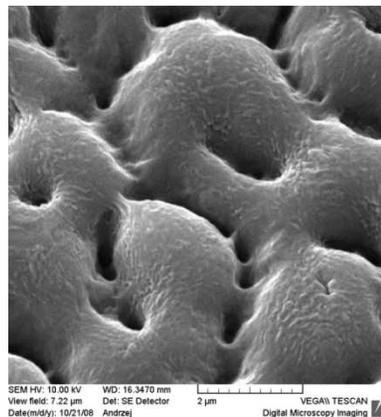


10 μm

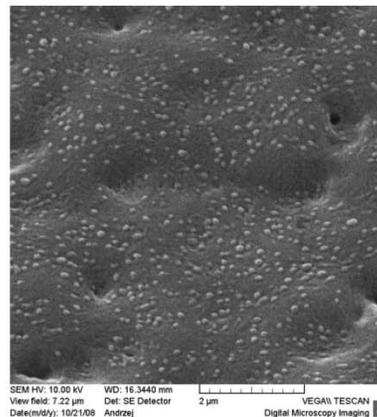


2 mm

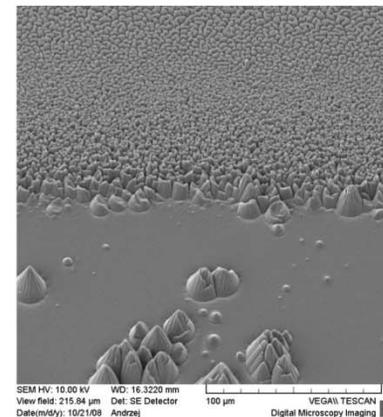
2 min exposure



2 μm



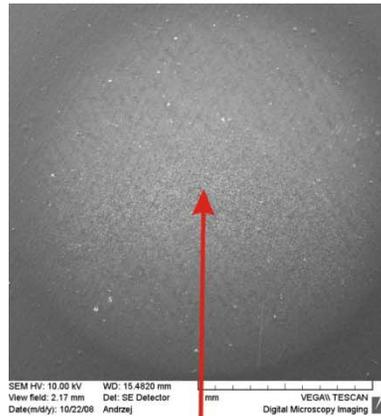
2 μm



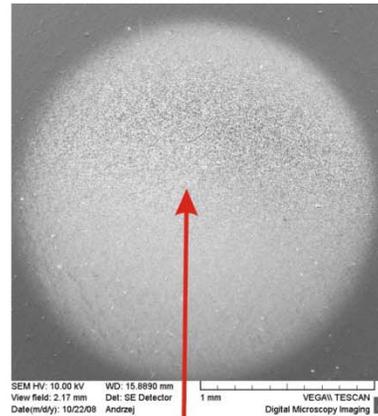
10 μm

Polyvinyl Fluoride (PVF)

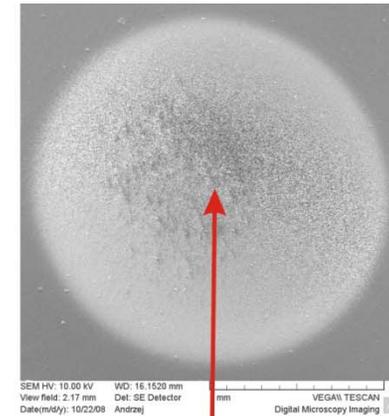
SEM images of PVF irradiated 3 mm behind the focal plane of Mo coated ellipsoidal collector, Xe plasma radiation, repetition rate 10 Hz



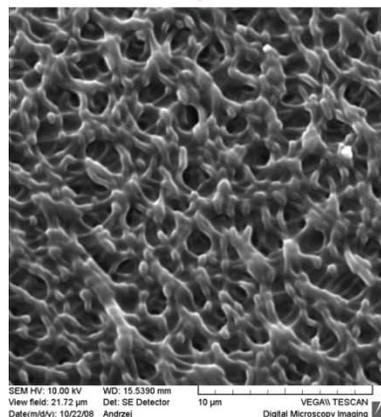
1 mm



1 mm

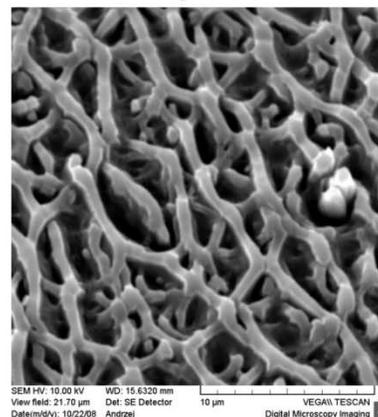


1 mm



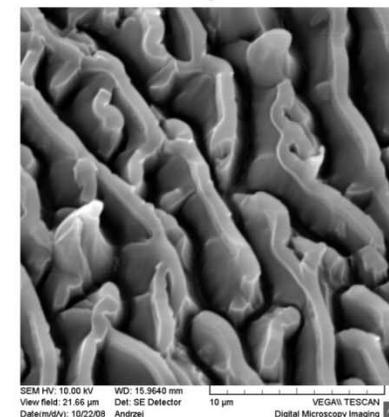
10 μm

5 s exposure



10 μm

10 s exposure

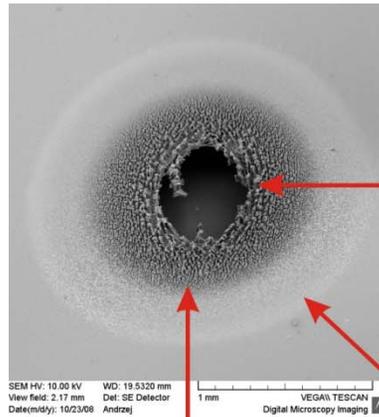


10 μm

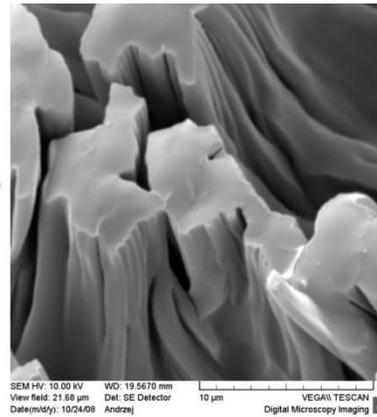
30 s exposure

Polystyrene (PS)

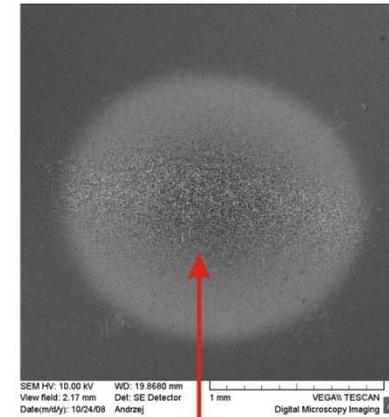
SEM images of PS irradiated in the focal plane of Mo coated ellipsoidal collector, Xe plasma radiation, repetition rate 10 Hz



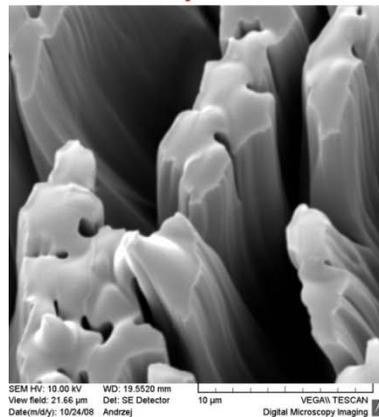
1 mm



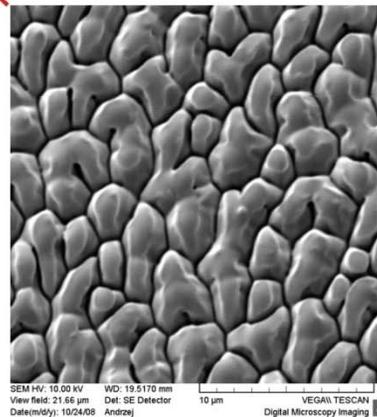
10 μm



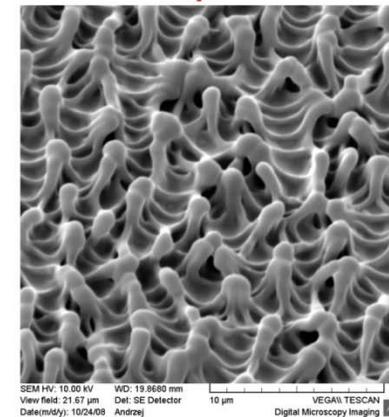
1 mm



10 μm



10 μm



10 μm

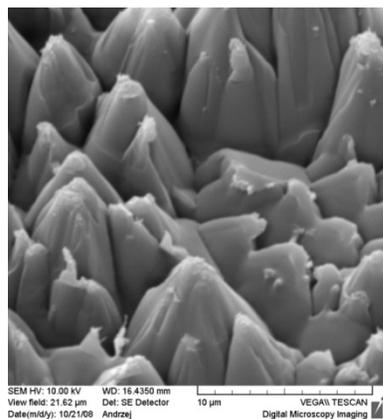
1 min exposure

2,5 s exposure

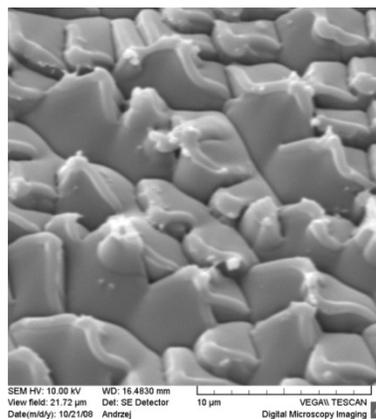
Polyethylene Terephthalate (PET)

SEM images of PET irradiated behind the focal plane of Mo coated ellipsoidal collector, Xe plasma radiation, repetition rate 10 Hz

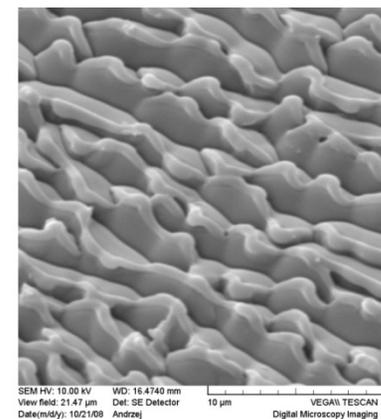
Central part



10 µm

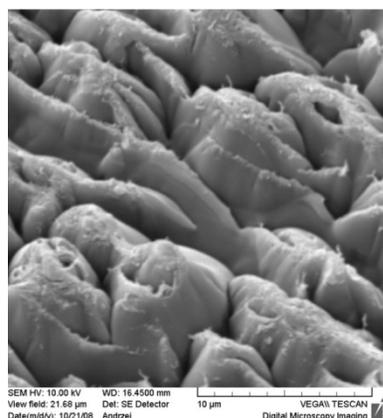


10 µm



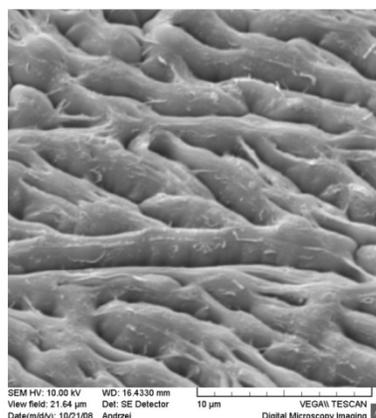
10 µm

Close to an edge of the focal spot



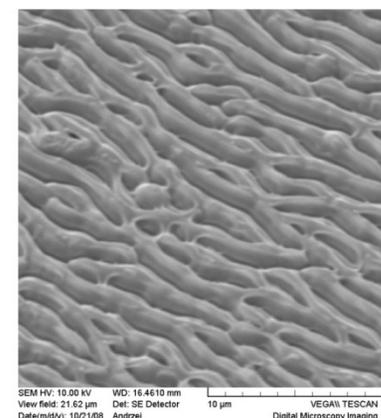
10 µm

1 min exposure



10 µm

30 s exposure



10 µm

10 s exposure

J. Heitz

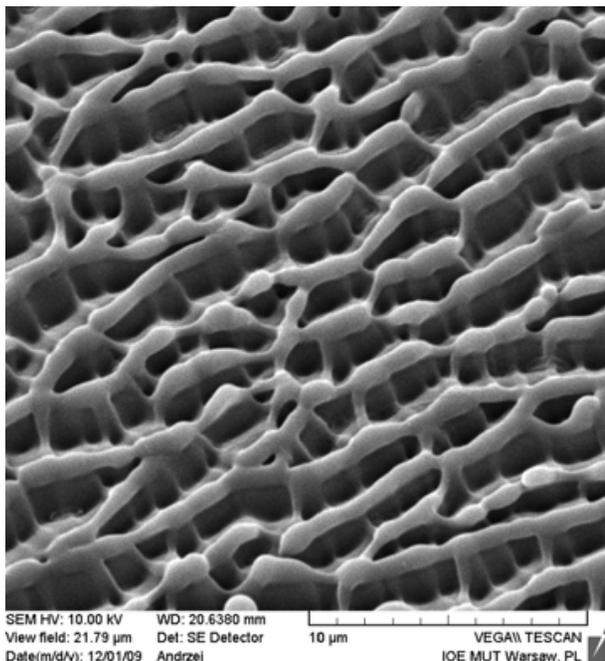


Applied Physics Linz

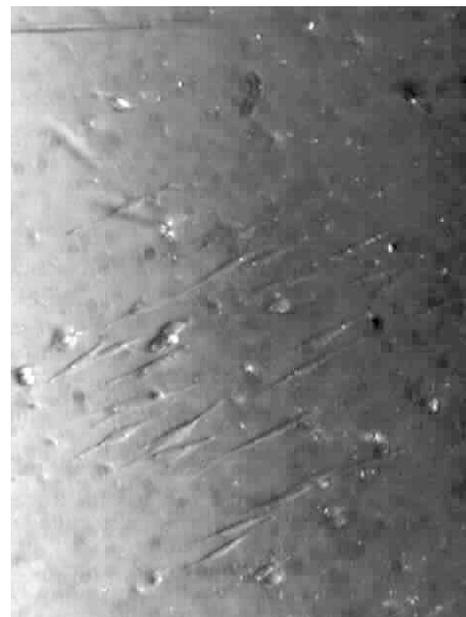


C. Romanin

SEM



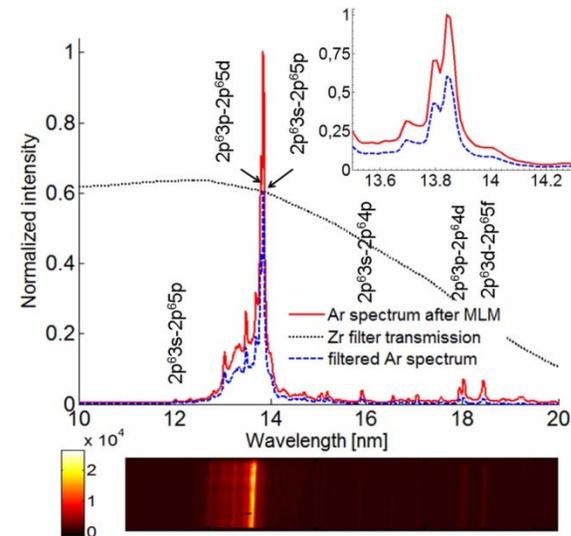
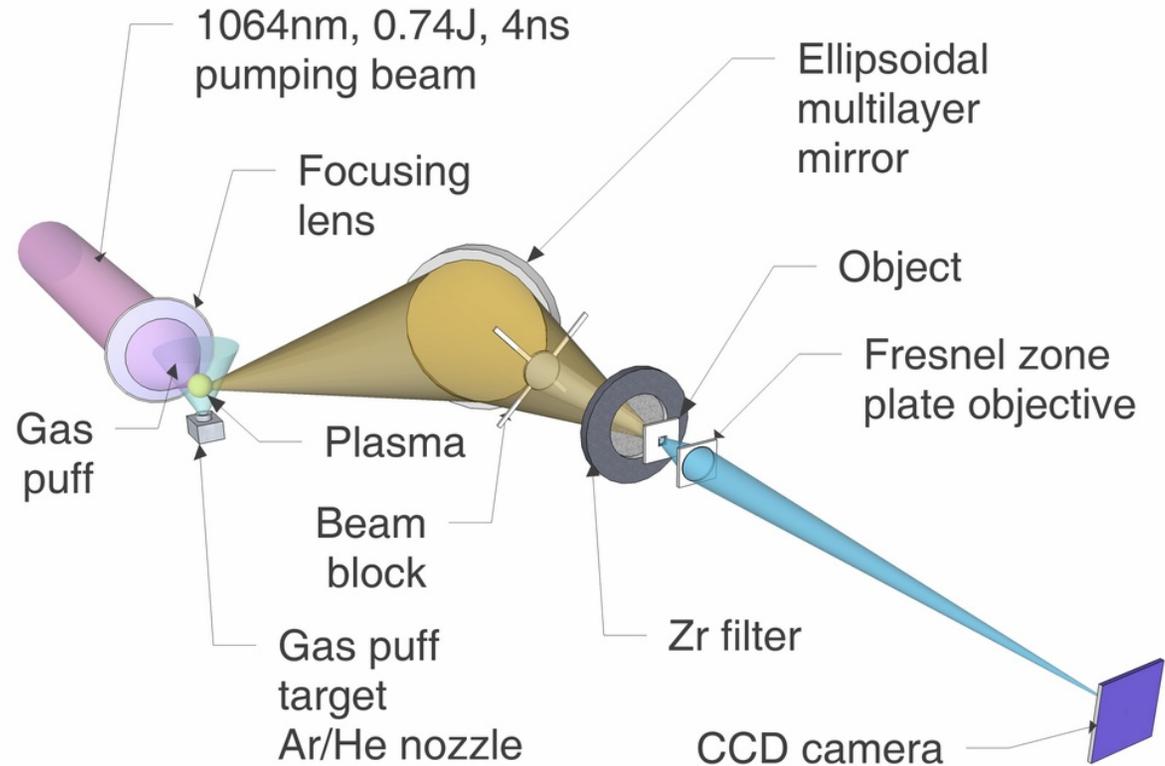
Phase Contrast Microscope



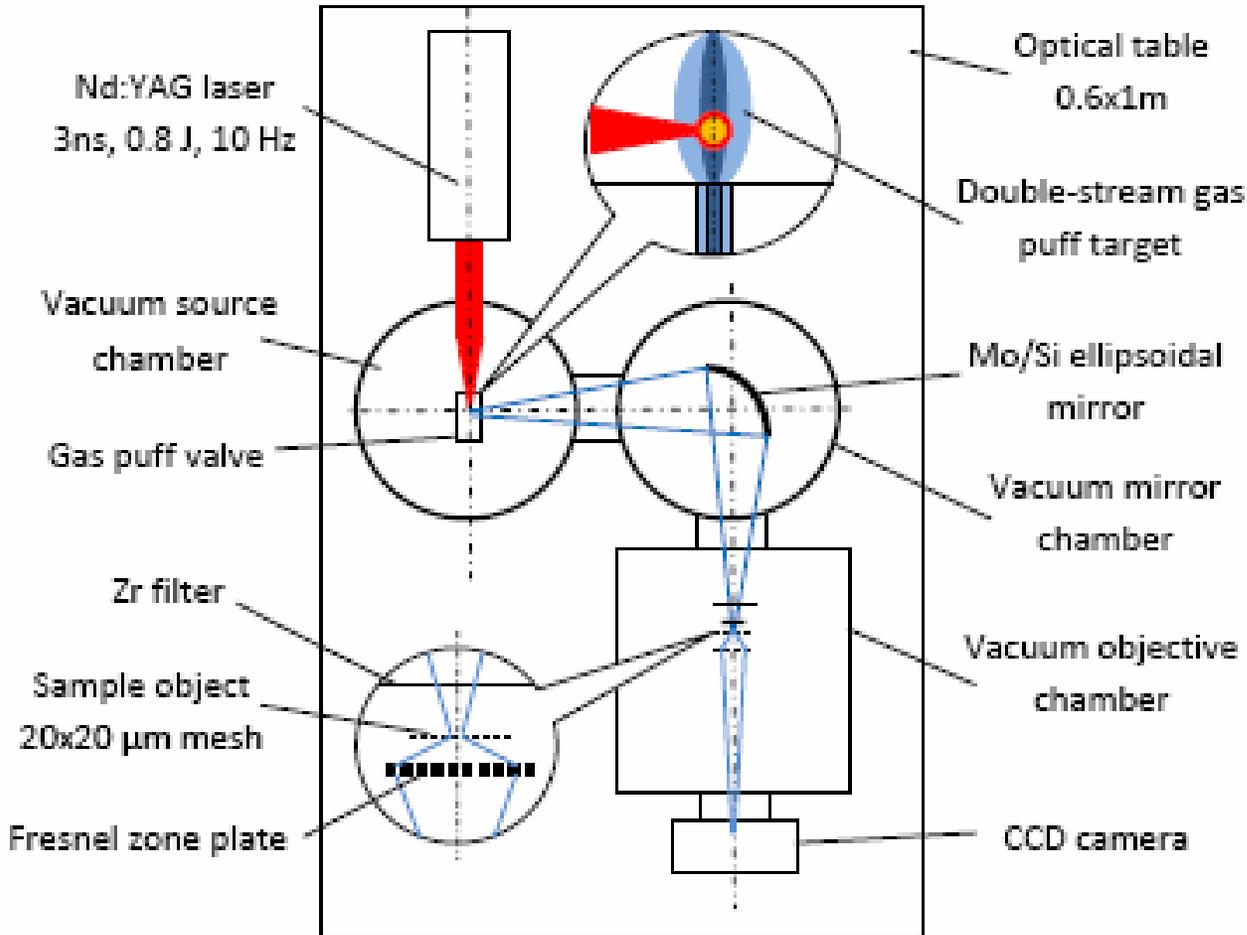
- good alignment of Chinese hamster ovary (CHO) cells along the direction of the walls was found,
- CHO cells showed only bad adhesion at the irradiated surfaces and no alignment for samples irradiated with UV laser at 193 nm,
- chemical surface modification is more pronounced for EUV irradiation.

Applied Physics A **100**, 511-516 (2010)

Scheme of the EUV microscope based on a Fresnel optics



Desk-Top EUV Nanoscope



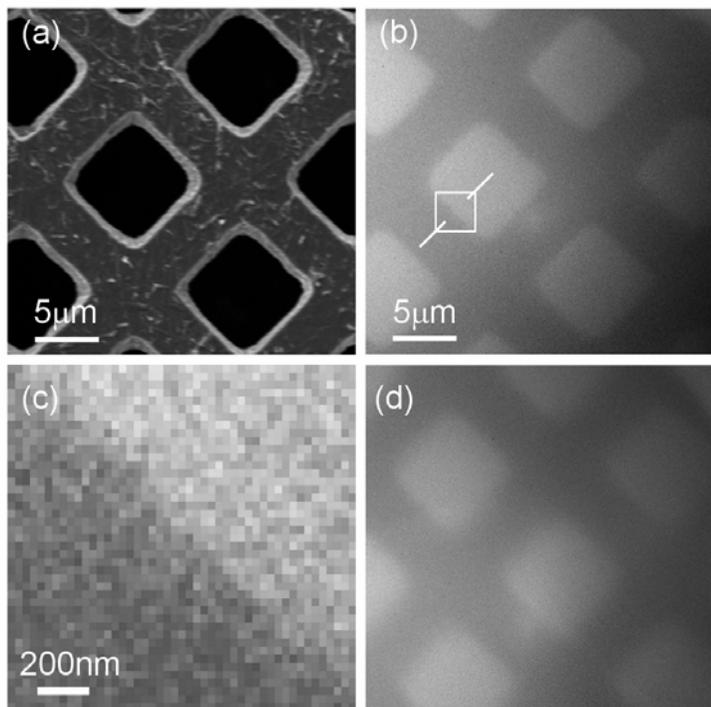
Fresnel zone plate

Outer zone width – 50 nm
Resolution – 61 nm

Nanoimaging using a Laser Plasma EUV Source

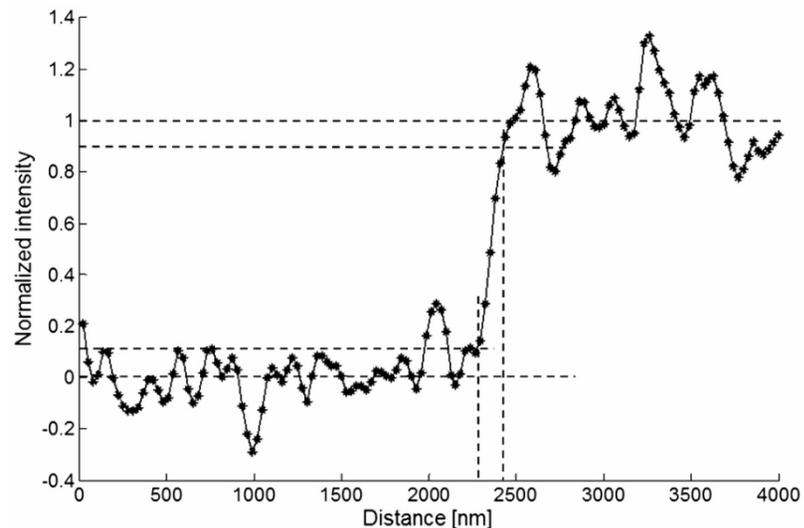
Sub-70nm resolution desk-top microscopy at 13.8 nm using a compact laser-plasma EUV source

- (a) SEM image of the copper mesh
- (b) EUV microscope image of the mesh



- (c) magnified EUV image
- (d) defocused EUV microscope image

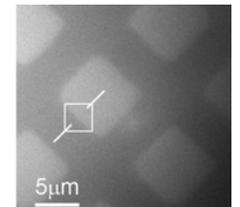
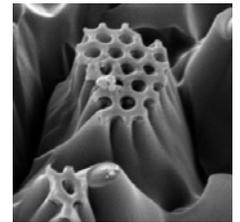
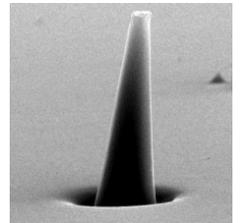
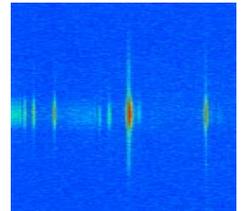
Knife-edge test for EUV image



Spatial resolution
69.4nm

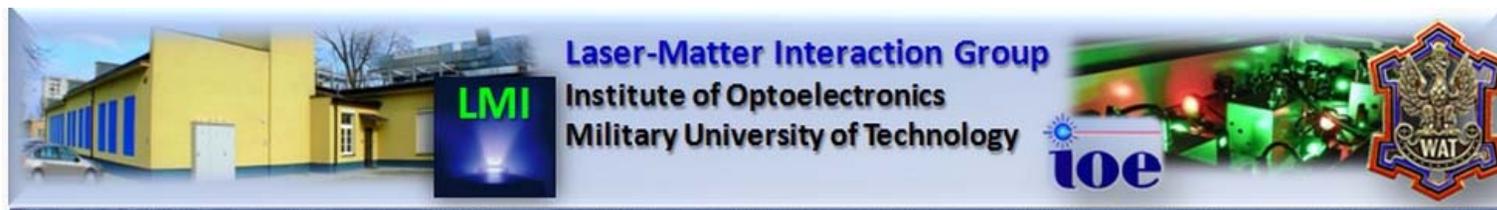
Conclusions

- **laser plasma soft X-ray and EUV sources** based on a gas puff target were introduced,
- laser plasma X-ray source for a **single shot exposure microscope** was demonstrated with the PALS facility
- **soft X-ray direct photo-etching polymers** was demonstrated using the laser plasma source with the PALS facility,
- compact laser plasma **EUV source for processing polymers** was developed,
- preliminary investigations on **modification of polymer surfaces** using EUV have been performed,
- **EUV microscope at 13.8 nm** based on a Fresnel optics have been proposed,
- **sub-70nm resolution** was demonstrated.



Short-Term Training in Processing Polymers using a Laser Plasma EUV Source

<http://www.ztl.wat.edu.pl/zoplzm>



Military University of Technology
Institute of Optoelectronics
Laser Technology Section

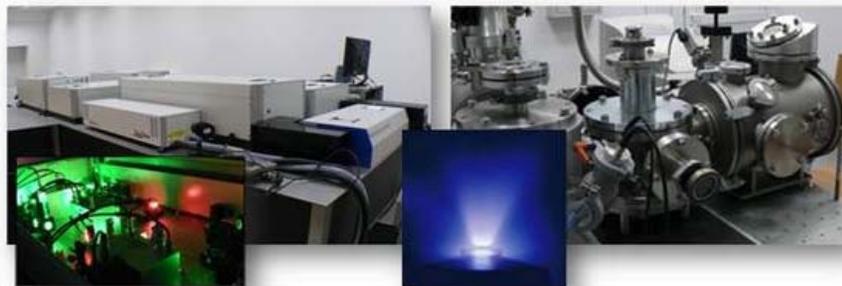
Home
Employees +
Publications
Current research
Trainings +
Achievements
Laboratories +
LMI Cooperation
Links
Students +
Contact +
Webmaster

Laser-Matter Interaction Group

The goal of the Laser-Matter Interaction Group is to develop short wavelength sources based on laser-matter interactions for applications in nanotechnology, solid state physics and material science among others.

Currently LMI group consists of nine researchers including one professor, six doctors and one master of science.

The group develops new methods of generating a short wavelength (soft X-ray and EUV) radiation based on the interaction of a laser light with the matter. Such a radiation is emitted from high temperature plasma generated by exciting the medium by a focused laser light.



As a result of research, conducted over many years by the LMI group, an appropriate medium for efficient EUV generation - gas puff target, was developed.



Monday
April 12, 2010

Students!



International Doctoral Studies under the Foundation for Polish Science MPD Programme (under evaluation)



COST MP0401

Short-Term Training in Processing Polymers using a Laser Plasma EUV Source

We provide:

- introduction
- EUV sources
- SEM
- AFM
- XPS

- accommodation
- meals

<http://www.ztl.wat.edu.pl/zoplzm>

